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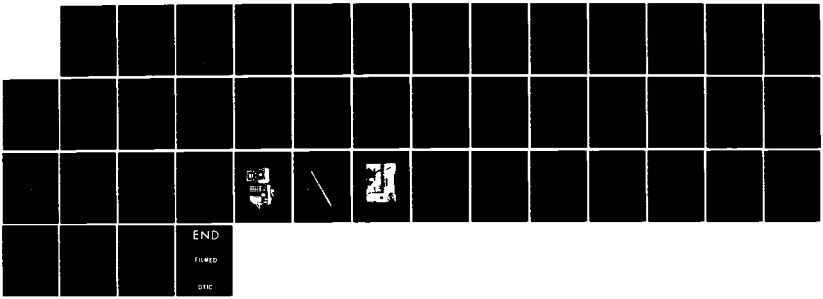

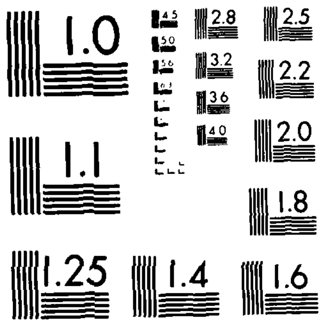

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MELBOURNE, VICTORIA

Structures Technical Memorandum 386

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CALIBRATION LOADING OF A STRAIN-GAUGED DIVERLESS HELICOPTER WEAPON RECOVERY SYSTEM

by

M. HELLER

A Diverless Helicopter Weapon Recovery System (DHWRS) has been strain gauged and subjected to ground calibration loadings.

A regression analysis has been carried out on the load/strain data and equations relating applied load to measured strain are presented for several locations, including the critical position on the aft ring.

Stress levels for a load of 24050N were calculated from the load/strain data.

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NOTATION

SYMBOLS

BF	Strain bridge factor
GF	Strain gauge factor
E	Modulus of elasticity
H	Hottinger reading
I	Second moment of area
L_R	Resultant load
L_C	Load cell reading of force
M	Bending moment
N_Y	Safety factor based on yield strength
P	Applied load
R	Radius of ring
r,θ,α	Polar co-ordinates
W	Weight of DHWRS
x,y,z	Cartesian co-ordinates
ε	Strain
σ	Stress
σ_y	Yield stress

Units

m	metre
mm	milli-metre
MPa	Mega pascal
μ	Micro
rad.	Radians

1. INTRODUCTION

This memorandum presents the results of a calibration loading test carried out on the Diverless Helicopter Weapon Recovery System (DHWRS), unit No. 3, at the Aeronautical Research Laboratories (ARL) on the 19th of October 1982.

The DHWRS is essentially an aluminium alloy (6061-T6) cage, suspended by a cable from a helicopter, that is used to recover Mk48 torpedoes from the sea. A sketch of the DHWRS is given in Figure 1, and a detailed description of the DHWRS structure and its operational use are given in Reference [1].

The calibration loading test was carried out at the request of the Director of Naval Aircraft Engineering (DNAE). It had been found that some DHWRS used in service had developed cracks at the welds in the aft ring. For this reason it was decided that the structural integrity of the DHWRS should be verified. This was done by a calibration loading test to determine the strains for typical loading conditions, and for a load of 24050N, which corresponds to the US Navy static proof load for the acceptance of the DHWRS.

The activities of ARL in relation to the calibration loading test of the DHWRS were essentially as follows:

(i) To attach strain gauges to critical positions of the aft ring.

(ii) To calibrate the strain gauges by incremental load application to a total load of 20900N.

(iii) To calculate - using the load/strain data - the stresses and hence the structural safety reserves at the critical positions of the aft ring for the US Navy Proof load of 24050N.

2. TEST METHOD

2.1 Strain Gauging

2.1.1 Strain gauge positions

Strain gauges were attached to critical positions (i.e. expected areas of maximum stresses) on the aft ring, and also to the strongback, and a barrel stave. The aft ring is shown in Figure 2.

Critical positions on the aft ring were determined as indicated in Appendix A. Strain gauges were attached to the aft ring at five locations, designated A,B,C,D and E2, as shown in Figure 3. At each of these positions, there were two active strain gauges wired into a Wheatstone bridge configuration.

Strain gauges were also attached to the strongback and to one barrel stave to provide further information concerning the level of strains and the transfer of loads in the DHWRS. The strain gauge position on the strongback was designated as position G and is shown in Figure 4. For this position, there were two active gauges wired into a Wheatstone bridge. The strain gauge position on the barrel stare was designated as position F, and is shown in Figure 5. At this position, there were four active gauges of which two were 'poisson' gauges, wired into the Wheatstone bridge.

The co-ordinates of all strain gauge positions are given in Table 1.

2.1.2 Temperature compensation

All of the Wheatstone strain bridges were temperature compensated electrically so that the bridge voltage outputs would be indpendent of temperature variation.

For each of the strain gauge positions A,B,C,D, E2 and G, temperature compensation was achieved by placing two bridge completion strain gauges on unstrained dummy plates, which were in good thermal contact with the structure, in the immediate vicinity of the two active gauges.

At position F temperature compensation was achieved through the correct wiring of the four active gauges in the bridge configuration.

2.1.3 Strain bridge voltage measurement instrumentaton

The strain bridge voltage measurement instrument used consisted of the ARL No. 1 Hottinger strain reading device and the ARL No. 2 Kyowa switching box. This instrumentation is shown in Figure 6.

All of the strain bridges were wired to the Kyowa switching box, which was used to electrically connect a particular strain bridge to a Hottinger strain reading device. The Hottinger supplied the strain bridge input voltage and gave an output reading to be used for the calculation of true strain.

2.2 Loading Method

The DHWRS was loaded in tension in the ARL No. 1 Univerisal testing machine using a reaction loading system. The loading method is shown schematically in Figure 7. The reaction loading system was used to transfer loads to the DHWRS, and consisted of a simulated Mk48 torpedo and a wiffle tree.

To simulate the torpedo a hollow rectangular section steel beam was fitted through the centre of three wooden blocks. The simulated torpedo was mounted inside the DHWRS with each of the wooden blocks located inside one of the three rings of the DHWRS, to facilitate the transfer of loads from the loading beam to the DHWRS.

The wiffle tree was bolted to the loading beam at a position such that when the DHWRS and the reaction loading system were mounted in the testing machine, the line of action of the applied load was equivalent to that for a DHWRS loaded with an actual Mk48 torpedo.

The DHWRS and the reaction loading system were installed in the testing machine with the wiffle tree fixed to the bottom machine grip and the strongback attached via links to the top machine grip, as shown in Figure 8.

2.3 Calibration Loading

Three loading runs were carried out. For each run, load and strain data were recorded as the DHWRS was loaded incrementally to a maximum value, and then unloaded incrementally. The tensile load applied to the strongback was measured using the No. 1 load cell from the ARL 'Revere' aircraft weighing kit, in conjunction with a compression cage.

The resultant load applied to the DHWRS by the reaction loading system is given by

$$L_R = L_C - W . \qquad ..(1)$$

At the initial strain datum L_R was 1179N (which was the weight of the reaction loading system).

Hence, to have load and strain reference levels corresponding, the load on the DHWRS is defined as

$$L = L_R - 1179 \qquad ..(2)$$

and upon substitution for L_R from equation (1), equation (2) becomes

$$L = L_C - 3182N . \qquad ..(3)$$

The calibration loading data for the three runs are given in Tables 2 to 8.

3. RESULTS

3.1 Calculation of Strains

Strains for all strain gauge positions were calculated from the Hottinger readings given in Tables 2 to 8, using the method indicated in Appendix B. The calculated strain values are also given in Tables 2 to 8, and are graphed in Figures 9 to 15.

3.2 Regression Curves for Strain Data

For each of the strain gauge positions A,C,D,E2,F and G, a single line was fitted to the combined load/strain results of run 1 loading and run 1 unloading, using polynomial regression. The axes for the regression lines were then translated to obtain equations where zero load corresponded to zero strain. These equations are given in Table 9.

Since the measured strains for strain gauge position B were low and highly variable, a regression line was not fitted to the data.

3.3 Stresses at 24050N Loading

To calculate the stress at a particular strain gauge position, for a load of 24050N, the local strain at that load is required.

The strains for all strain gauge positions, apart from position B, were calculated using the equations given in Table 9, and these strains are given in Table 10.

The strain for strain gauge position B was determined by inspection of Figure 10, and is also given in Table 10.

Stress values and safety factors for all strain gauge positions for a 24050N loading were calculated using equations (4) and (5) respectively, and are listed in Table 10.

$$\sigma = E \varepsilon \qquad ..(4)$$

where $E = 6.89 \times 10^9$ Pa for Al Alloy 6061-T6

and
$$N_y = \frac{\sigma_y}{\sigma} \qquad ..(5)$$

where $\sigma_y = 275.8$ MPa.

4. DISCUSSION OF RESULTS

4.1 Structural Hysteresis

Inspection of the strain results in Figures 9 to 15 indicates that there is structural hysteresis at all of the strain gauge positions, except for position G. The hysteresis could either be due to the DHWRS structure, or the reaction loading system.

Position G is very close to the loading point on the strongback (see Figure 4), and so strain results there would be expected to be unaffected by DHWRS structural hysteresis. Since the strain results at position G show no hysteresis, it can be concluded that the hysteresis indicated by the strain results at all other gauge positions was only due to the DHWRS structure.

Hence, it can be expected that when the DHWRS is used in service there will be some variability in strains due to structural hysteresis.

4.2 Strains at Gauge Position B

The measured strains for position B (see Figure 10) are low and highly variable, showing no simple correlation with applied load.

4.3 Stresses in Aft Ring at 24050N Loading

The results given in Table 10 show that the maximum stress region is at strain gauge position A, with the safety factor N_y being 1.74 for a 24050N loading.

It was expected that the stresses at positions C and D would be the same, however, the calculated values given in Table 10 show that the stress at position C is approximately 22% higher than that at position D. However, this is not considered to be important, since these stresses are approximately 50% less than those at position A.

4.4 Stresses at Position F for 24050N Loading

The calculated stress for position F (see Table 10), is very low, and indicates that only a minimal amount of load is transfered to the barrel stares.

5. CONCLUSION

The maximum stress location in the aft ring is at position A. For the U.S. Navy Proof load of 24050N, the stress level was estimated as being 158 MPa. This stress level corresponds to a safety factor based on yield strength of 1.74.

REFERENCES

1. — US Department of the Navy. Technical Manual SW591-BØ-MMO-Ø1Ø/WPN RECOV SYS NAVAIR 11-9Ø-2. Commander, Naval Sea Systems Command. Feb. 1979.

2. Bruhn, E.F. Analysis and Design of Flight Vehicle Structures. Tri-State Offset Company, Ohio, 1965.

APPENDIX A

Determination of Strain Gauge Locations on the Aft Ring

In this Appendix, the locations of expected maximum stresses (i.e. critical locations) on the aft ring of a loaded DHWRS are determined. Strain gauges are to be placed at these locations.

A.1 LOADING OF DHWRS

Upon recovery of the Mk48 torpedo from the sea, the loading of the DHWRS is as shown in Figure A.1.

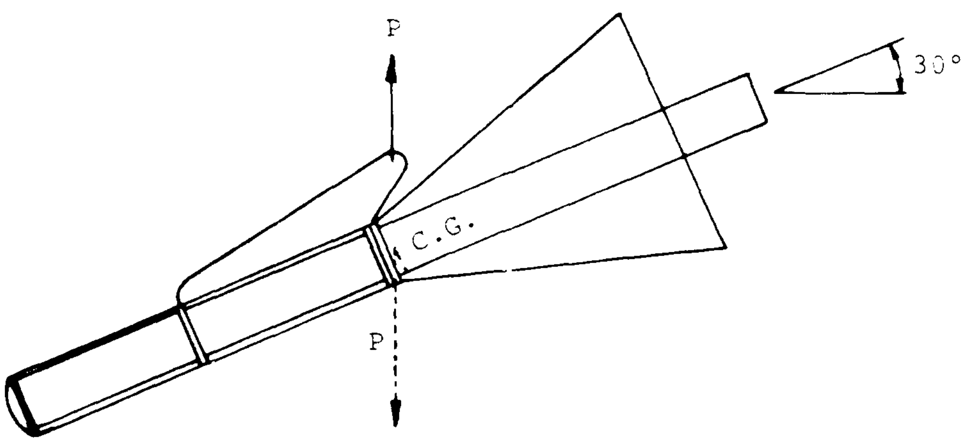

FIGURE A.1

For static equilibrium, the DHWRS is inclined at 30° to the horizontal, and the centre of gravity (C.G.) of the Mk48 torpedo is very close to the aft ring. Hence, as a conservative assumption, it is assumed that the total load P is taken by the aft ring alone.

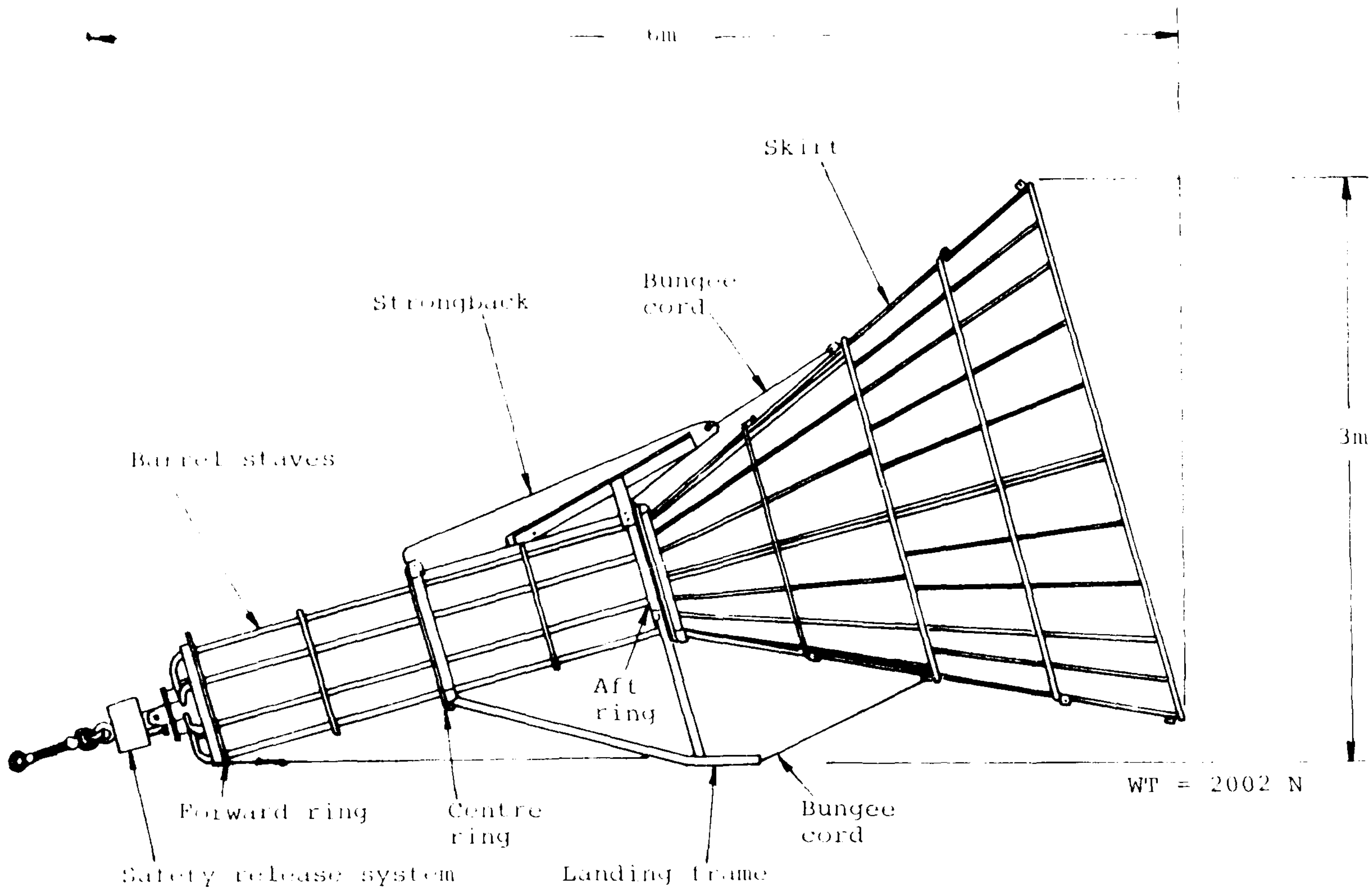

FIG. 1 DIVERLESS HELICOPTER WEAPONS RECOVERY SYSTEM

TABLE 10

CALCULATED STRESS VALUES FOR LOAD OF 24050N

GAUGE POSITION	STRAIN ($\mu\varepsilon$)	STRESS (MPa)	SAFETY FACTOR
A	2298	158.3	1.74
B	- 62.0	4.30	64.2
C	- 1328	91.5	3.01
D	- 1040	71.6	3.85
E2	381.0	26.3	10.5
F	118.3	8.13	33.9
G	782.0	53.9	5.10

TABLE 9

REGRESSION EQUATIONS FOR LOAD VERSUS STRAIN RESULTS

GAUGE POSITION	EQUATIONS OF LOAD VERSUS STRAIN (lb)
A	$L = 8.466\ \varepsilon + 0.000868\ \varepsilon^2$; for $\varepsilon \geqslant 0$
C	$L = -16.0\ \varepsilon + 0.001583\ \varepsilon^2$; for $\varepsilon \leqslant 0$
D	$L = -15.19\ \varepsilon + 0.00763\ \varepsilon^2$; for $\varepsilon \leqslant 0$
E2	$L = 62.20\ \varepsilon + 0.0056\ \varepsilon^2$; for $\varepsilon \geqslant 0$
F	$L = 138.4\ \varepsilon + 7670$; for $\varepsilon > 0$
G	$L = 30.74\ \varepsilon$; for $\varepsilon \geqslant 0$

TABLE 8

STRAIN DATA FOR GAUGE POSITION G

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	27209	0
		1304	27296	41.4
		5789	27600	186
		10217	27898	328
		14686	28206	475
		19125	28506	618
		20868	28637	680
	UNLOADING	19141	28527	628
		14673	28213	478
		10141	27902	330
		5721	27305	187
		1286		45.7
2	LOADING	9	27217	3.8
		1312	27306	46.2
		3266	27438	109
		5731	27600	186
		7553	27717	242
		10258	27907	332
	UNLOADING	7578	27715	241
		5731	27590	181
		3157	27422	101
		1084	27286	36.7
3	LOADING	3	27217	3.8
		1387	27312	49.0
		3272	27438	109
		5753	27603	188
		7670	27733	250
		10293	27910	279
	UNLOADING	7578	27714	240
		5722	27590	181
		3177	27422	101
		1279	27299	42.9
		- 42	27216	3.3

TABLE 7

STRAIN DATA FOR GAUGE POSITION F

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	26508	0
		1304	26489	- 6.9
		5789	26417	- 33.0
		10217	26548	14.5
		14686	26660	55.2
		19125	26758	90.7
		20868	26792	103
	UNLOADING	19141	26763	92.6
		14673	26684	63.9
		10141	26603	34.5
		5721	26527	6.9
		1286	26550	15.2
2	LOADING	9	26556	17.4
		1312	26532	8.7
		3266	26498	- 3.6
		5731	26473	- 12.7
		7553	26507	- 0.4
		10258	26565	20.7
	UNLOADING	7578	26524	5.8
		5731	26500	- 2.9
		3157	26527	6.89
		1084	26548	14.5
3	LOADING	3	26555	17.1
		1387	26530	8.0
		3272	26497	- 4.0
		5753	26468	- 14.5
		7670	26504	- 1.45
		10293	26566	21.0
	UNLOADING	7578	26522	5.1
		5722	26500	- 2.9
		3177	26527	6.9
		1279	26546	13.8
		- 42	26556	17.4

TABLE 6

STRAIN DATA FOR GAUGE POSITION E2

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	28143	0
		1304	28178	16.5
		5789	28308	77.8
		10217	28467	152
		14686	28619	225
		19125	28778	300
		20868	28849	333
	UNLOADING	19141	28795	308
		14673	28646	237
		10141	28500	168
		5721	28362	103
		1286	28225	38.7
2	LOADING	9	28186	20.3
		1312	28223	37.7
		3266	28282	65.6
		5731	28353	99.1
		7553	28407	125
		10258	28497	167
	UNLOADING	7578	28410	126
		5731	28353	99.5
		3157	28280	64.6
		1084	28217	34.9
3	LOADING	3	28184	19.4
		1387	28225	38.7
		3272	28282	65.6
		5753	28354	99.5
		7670	28414	128
		10293	28498	167
	UNLOADING	7578	28409	126
		5722	28353	99.1
		3177	28280	64.6
		1279	28222	37.3
		- 42	28184	19.3

TABLE 5

STRAIN DATA FOR GAUGE POSITION D

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	26979	0
		1304	26811	- 79
		5789	26296	- 322
		10217	25870	- 523
		14686	25515	- 691
		19125	25224	- 828
		20868	25112	- 881
	UNLOADING	19141	25260	- 811
		14673	25708	- 600
		10141	26187	- 374
		5721	26676	- 143
		1286	27169	90
2	LOADING	9	27310	156
		1312	27143	77
		3266	26912	- 31.6
		5731	26637	- 161
		7553	26446	- 251
		10258	26141	- 395
	UNLOADING	7578	26451	- 249
		5731	26660	- 150
		3157	26948	- 14.6
		1084	27189	99
3	LOADING	3	27312	157
		1387	27136	74
		3272	26913	- 31
		5753	26635	- 162
		7670	6420	- 264
		10293	[illegible]6135	- 398
	UNLOADING	7578	26454	- 248
		5722	26662	- 149
		3177	26947	- 15
		1279	27166	88
		- 42	27313	158

TABLE 4

STRAIN DATA FOR GAUGE POSITION C

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	24649	0
		1304	24490	- 75
		5789	24015	- 299
		10217	23497	- 543
		14686	22965	- 794
		19125	22375	- 1073
		20868	22131	- 1187
	UNLOADING	19141	22282	- 1116
		14673	22744	899
		10141	23229	- 670
		5721	23722	- 437
		1286	24230	- 198
2	LOADING	9	24384	- 125
		1312	24227	- 199
		3266	24007	- 303
		5731	23740	- 429
		7553	23552	- 517
		10258	23244	- 663
	UNLOADING	7578	23544	- 521
		5731	23747	- 425
		3157	24025	- 294
		1084	24263	- 182
3	LOADING	3	24387	- 124
		1387	24221	- 201
		3272	24007	- 303
		5753	23738	- 430
		7670	23528	- 529
		10293	23240	- 665
	UNLOADING	7578	23549	- 519
		5722	23752	- 423
		3177	24025	- 294
		1279	24242	- 192
		-42	24388	- 123

TABLE 3

STRAIN DATA FOR GAUGE POSITION B

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	28161	0
		1304	28164	1.4
		5789	28182	9.9
		10217	28045	- 54.7
		14686	28028	- 62.7
		19125	28084	- 36.3
		20868	28114	- 22.2
	UNLOADING	19141	28217	26.4
		14673	28286	58.9
		10141	28111	- 23.6
		5721	28011	- 70.7
		1286	28090	- 33.5
2	LOADING	9	28168	3.3
		1312	28157	- 1.9
		3266	28178	8.0
		5731	28184	10.8
		7553	28145	- 7.5
		10258	28092	- 32.5
	UNLOADING	7578	28097	- 30.2
		5731	28073	- 41.5
		3157	28045	- 55.7
		1084	28084	- 36.3
3	LOADING	3	28140	- 9.9
		1387	28131	- 14.2
		3272	28160	- 0.5
		5753	28179	8.5
		7670	28147	- 6.6
		10293	28090	- 33.3
	UNLOADING	7578	28096	- 30.7
		5722	28071	- 42.5
		3177	28036	- 58.9
		1279	28078	- 39.2
		- 42	28179	- 15.1

TABLE 2

STRAIN DATA FOR GAUGE POSITION A

RUN NUMBER		LOAD (N)	HOTTINGER READING H_x	STRAIN ($\mu\varepsilon$)
1	LOADING	0	24348	0
		1304	24655	145
		5789	25590	586
		10217	26550	1039
		14686	27478	1476
		19125	28356	1891
		20868	28700	2053
	UNLOADING	19141	28435	1928
		14673	27665	1565
		10141	26788	1151
		5721	25856	711
		1286	24928	274
2	LOADING	9	24662	148
		1312	24963	290
		3266	25386	490
		5731	25885	725
		7553	26210	878
		10258	26769	1142
	UNLOADING	7578	26178	863
		5731	25797	683
		3157	25266	433
		1084	24841	233
3	LOADING	3	24639	137
		1387	24957	287
		3272	25374	484
		5753	25883	724
		7670	26262	903
		10293	26770	1142
	UNLOADING	7578	26170	859
		5722	25787	679
		3177	25264	432
		1279	24875	249
		- 42	24630	133

TABLE 1

CO-ORDINATES OF STRAIN GAUGE POSITIONS

GAUGE DESIGNATION	NO	CO-ORDINATES		
		θ (rad)	x (mm)	r (mm)
A	1	- 0.01240	6.35	403.22
	2	+ 0.01240	6.35	403.22
B	1	- 0.01486	74.2	336.55
	2	+ 0.01486	74.2	336.55
C	1	1.5584	6.35	403.22
	2	1.5832	6.35	403.22
D	1	- 1.5832	6.35	403.22
	2	- 1.5584	6.35	403.22
E2	1	1.5565	71.2	336.55
	2	1.5851	71.2	336.55
F	1	0.0	65.0	-
	2	+ 1.571	78.0	-
	3	0.0	92.0	-
	4	- 1.571	78.0	-
G	1	-	-167	6.35
	2	-	-177	6.35

APPENDIX B

Calculation of Strains

B.1 STRAIN BRIDGE DATA

The Hottinger gauge factor HGF, the strain bridge factor BF, and the strain gauge factor GF, for each strain position are given below in Table B.1.

TABLE B.1

GAUGE POSITION	HGF	BF	GF
A	2	2	2.12
B	2	2	2.12
C	2	2	2.12
D	2	2	2.12
E2	2	2	2.12
F	2	2.6	2.756
G	2	2	2.10

B.2 STRAIN EQUATION

Strains are calculated from the Hottinger readings and the bridge data by

$$\varepsilon = \frac{(H_x - H_o) \cdot HGF}{GF.BF} \qquad ..(B.1)$$

where H_x = Hottinger reading at load x

H_o = Hottinger reading at zero load.

A.3 STRESSES IN AFT RING AND STRAIN GAUGE LOCATIONS

At any section of the aft ring the resultant stresses will be due to a combination of stresses due to bending and the stresses due to axial loading.

The bending stress will be a maximum at the extreme fibres (i.e. positions furthest from the sectional principal axes) of sections of maximum bending moment, (i.e. at $\theta=0°$ and $\theta=90°$).

The stress due to axial loading will be a maximum at $\theta=90°$ and constant across the section.

Hence, the maximum resultant stresses will occur at the sections of maximum bending moment at the extreme fibres. That is, at $\theta=0°$ and $\theta=90°$, and this is where the strain gauges should be positioned.

A.2 LOADING OF THE AFT RING

The aft ring is assumed to be loaded in tension as shown in Figure A.2.

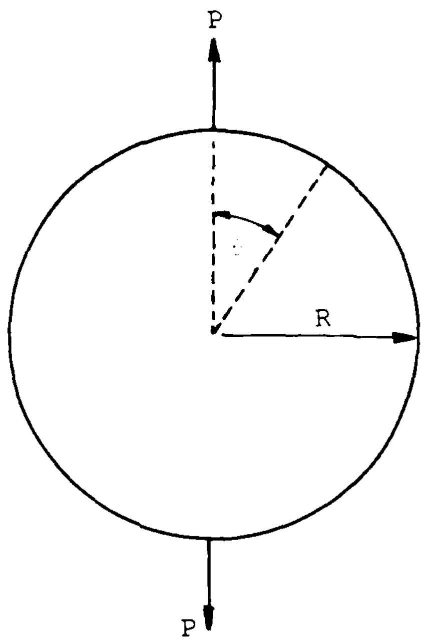

FIGURE A.2

This loading results in a bending moment distribution around the ring given by

$$M = PR\left(\frac{1}{2} - \sin\theta\right) \qquad ..(A.2)$$

Hence, Maximum positive M at θ = 0°, 180°

Maximum negative M at θ = -90°, 90°.

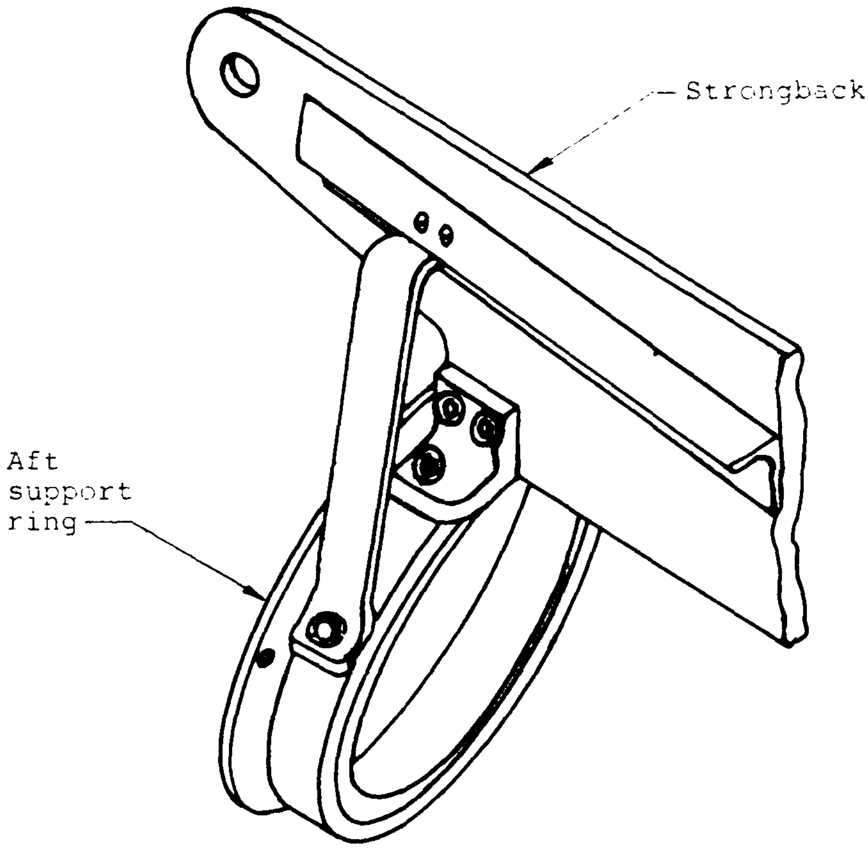

FIG. 2 AFT RING - STRONGBACK ASSEMBLY

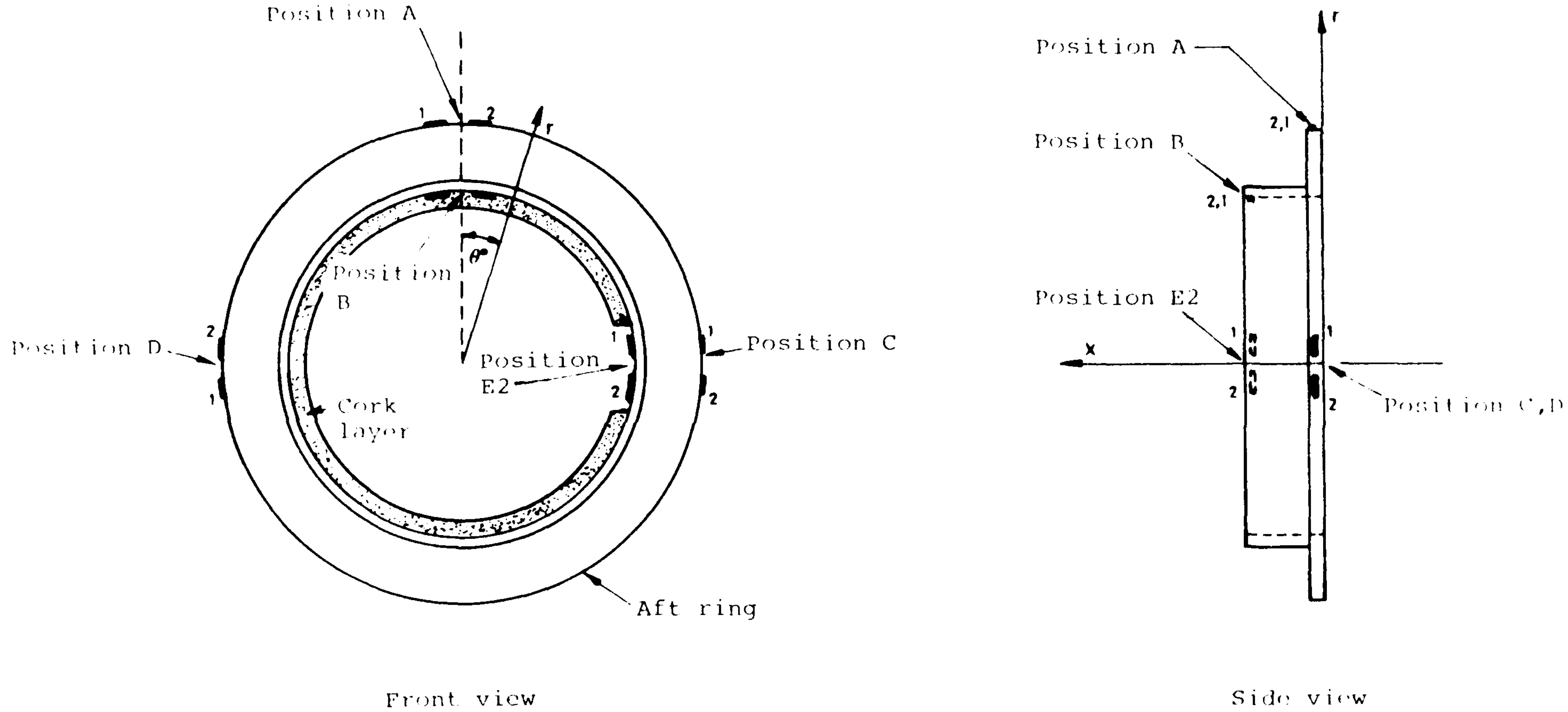

FIG. 3 AFT RING GAUGE POSITIONS AND CO-ORDINATE AXES

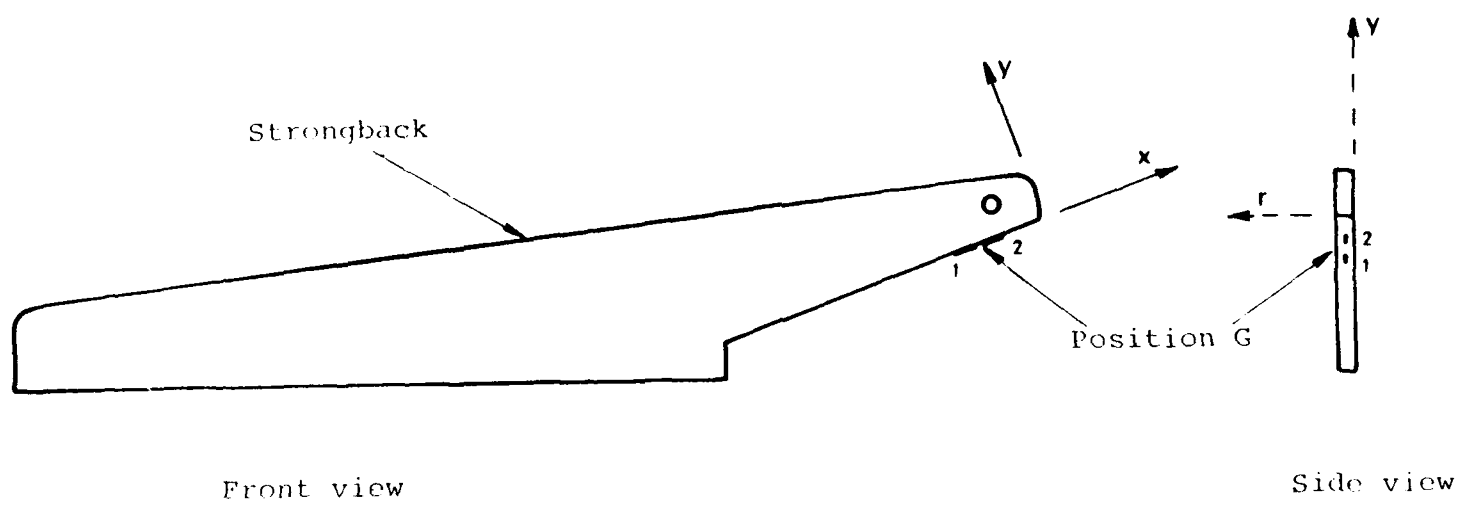

FIG. 4 STRONGBACK GAUGE POSITION AND CO-ORDINATE AXIS

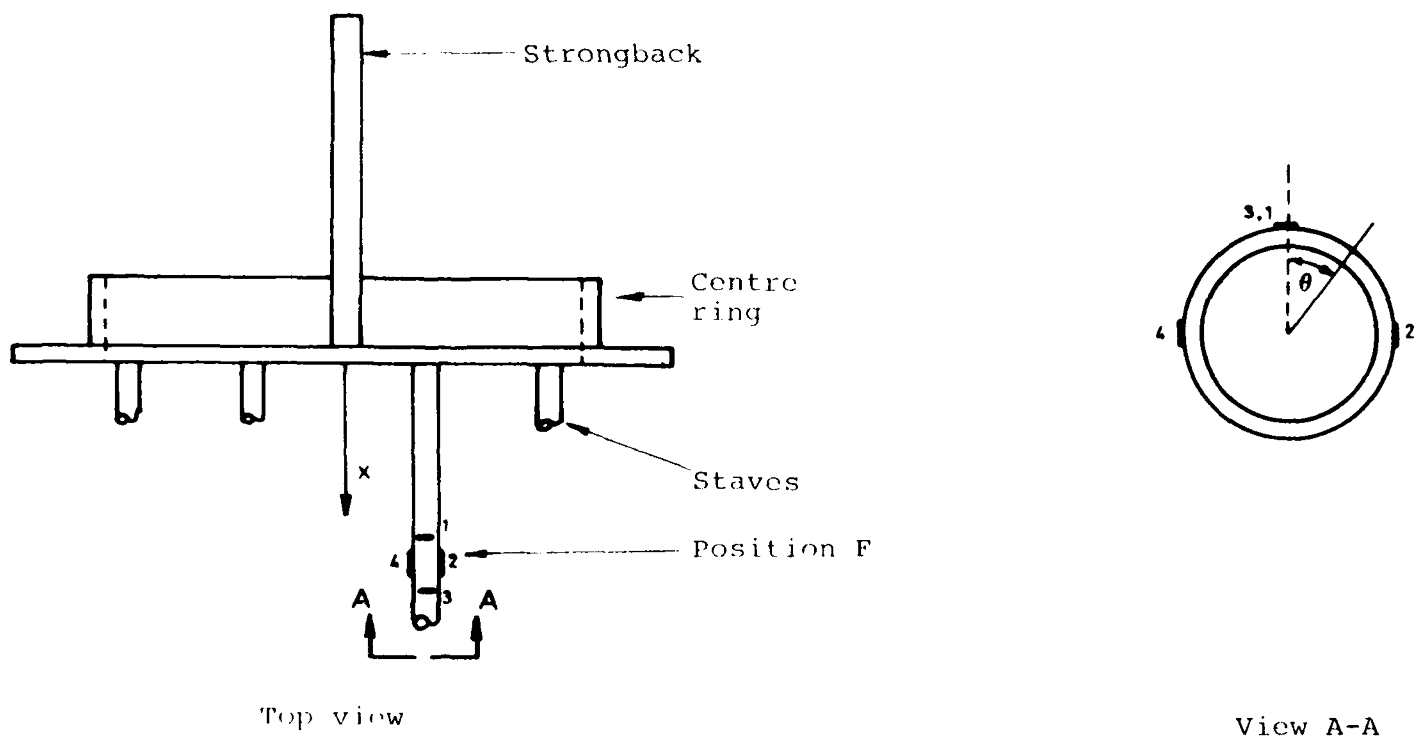

FIG. 5 BARREL STAVE GAUGE POSITION AND CO-ORDINATE AXES

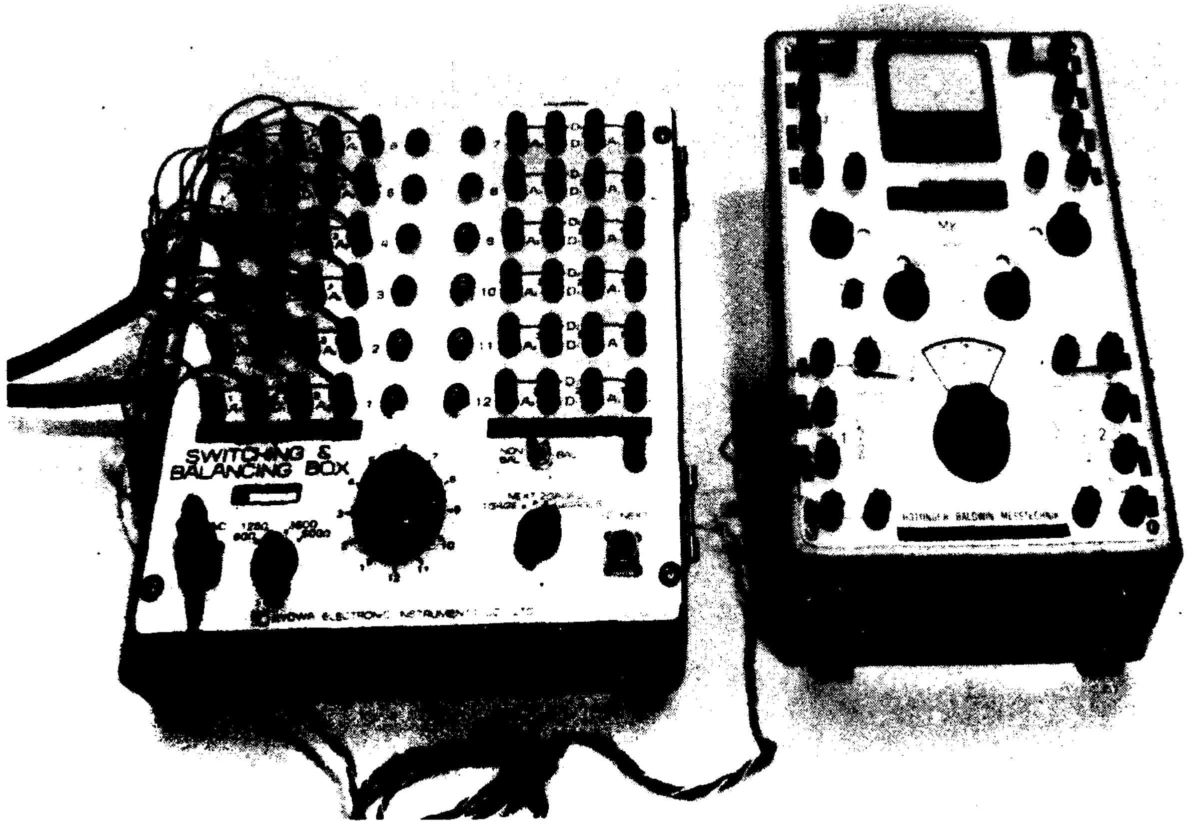

FIG. [illegible] KYOWA SWITCHING BOX (LEFT) AND HOTTINGER STRAIN [illegible] (RIGHT)

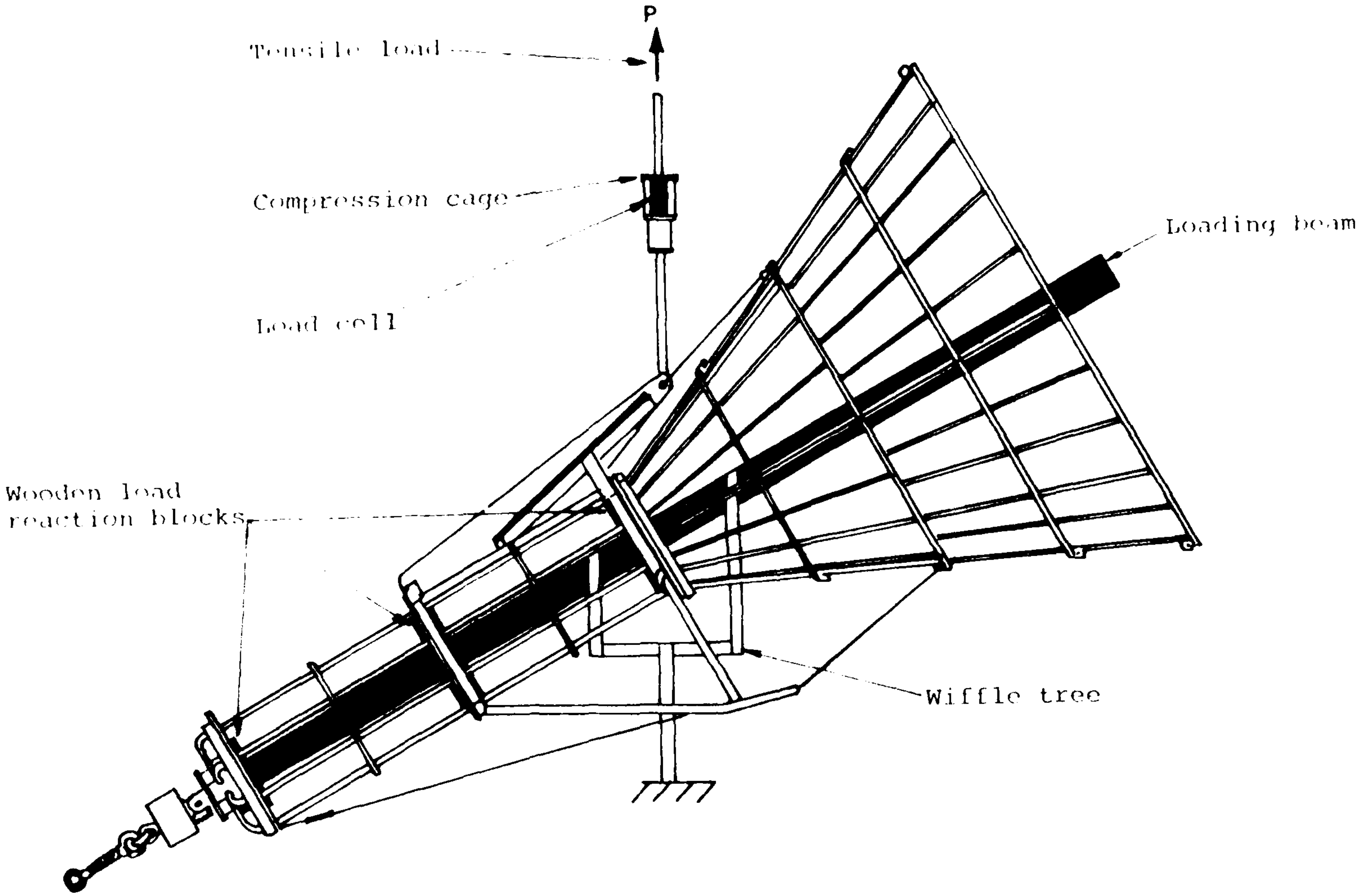

FIG. 7 TEST LOADING SYSTEM

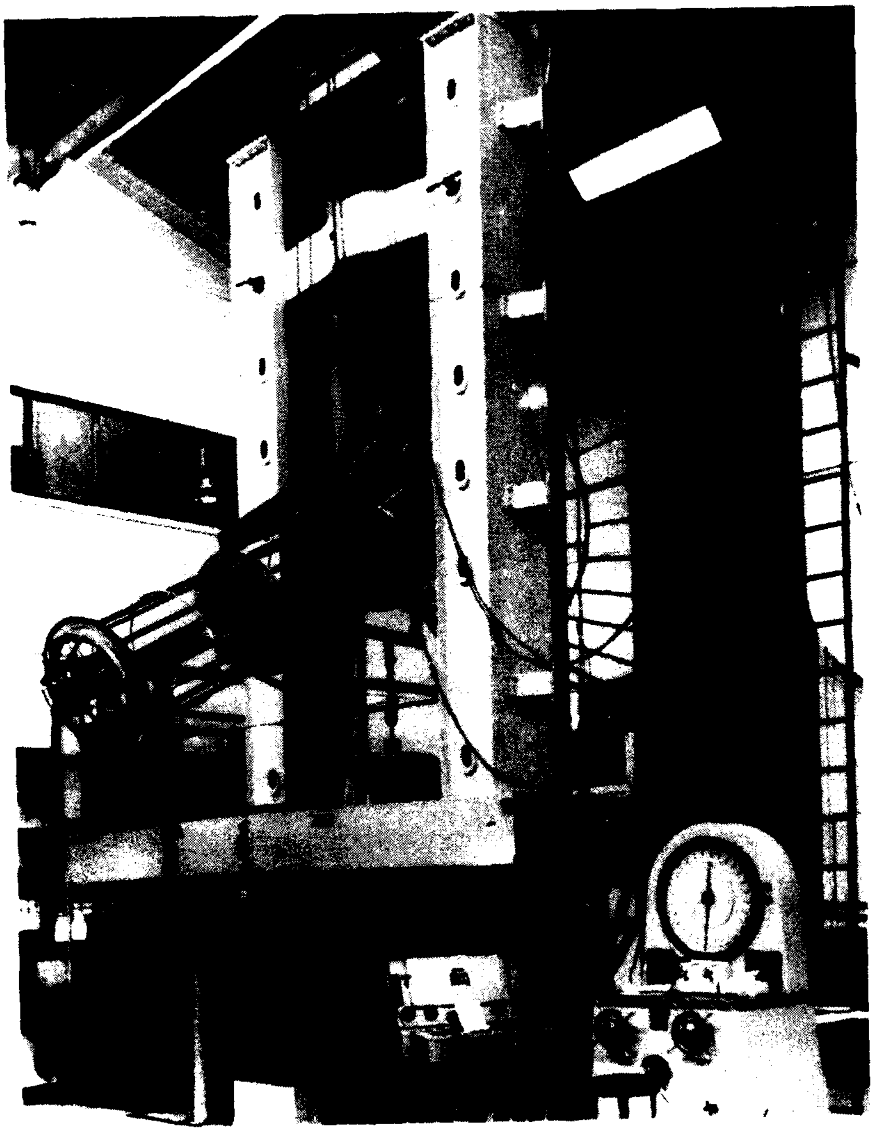

FIG. 8 DHWRS AND LOADING SYSTEM INSTALLED IN ARL UNIVERSAL TESTING MACHINE

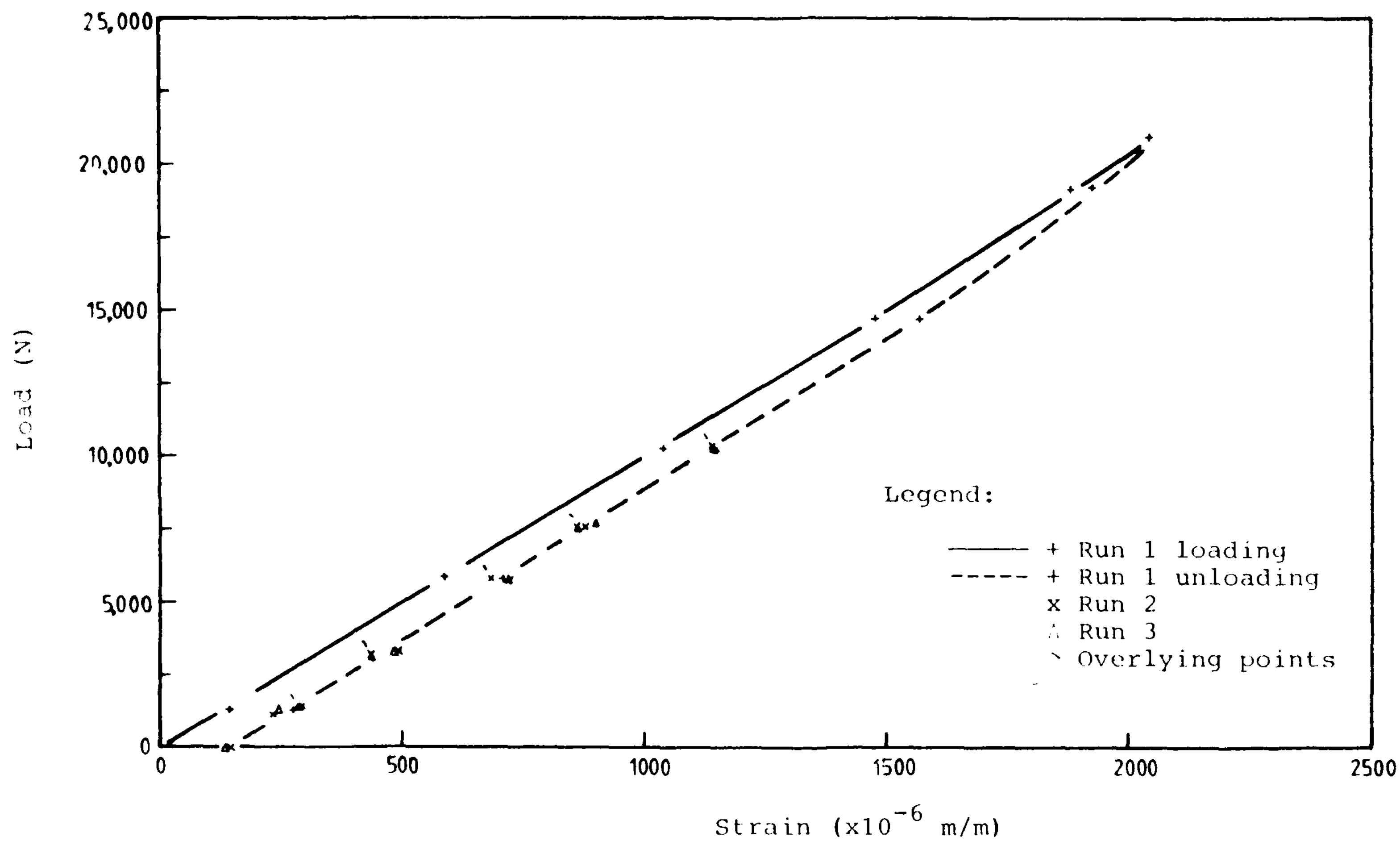

FIG. 9 LOAD VERSUS STRAIN FOR GAUGE POSITION A

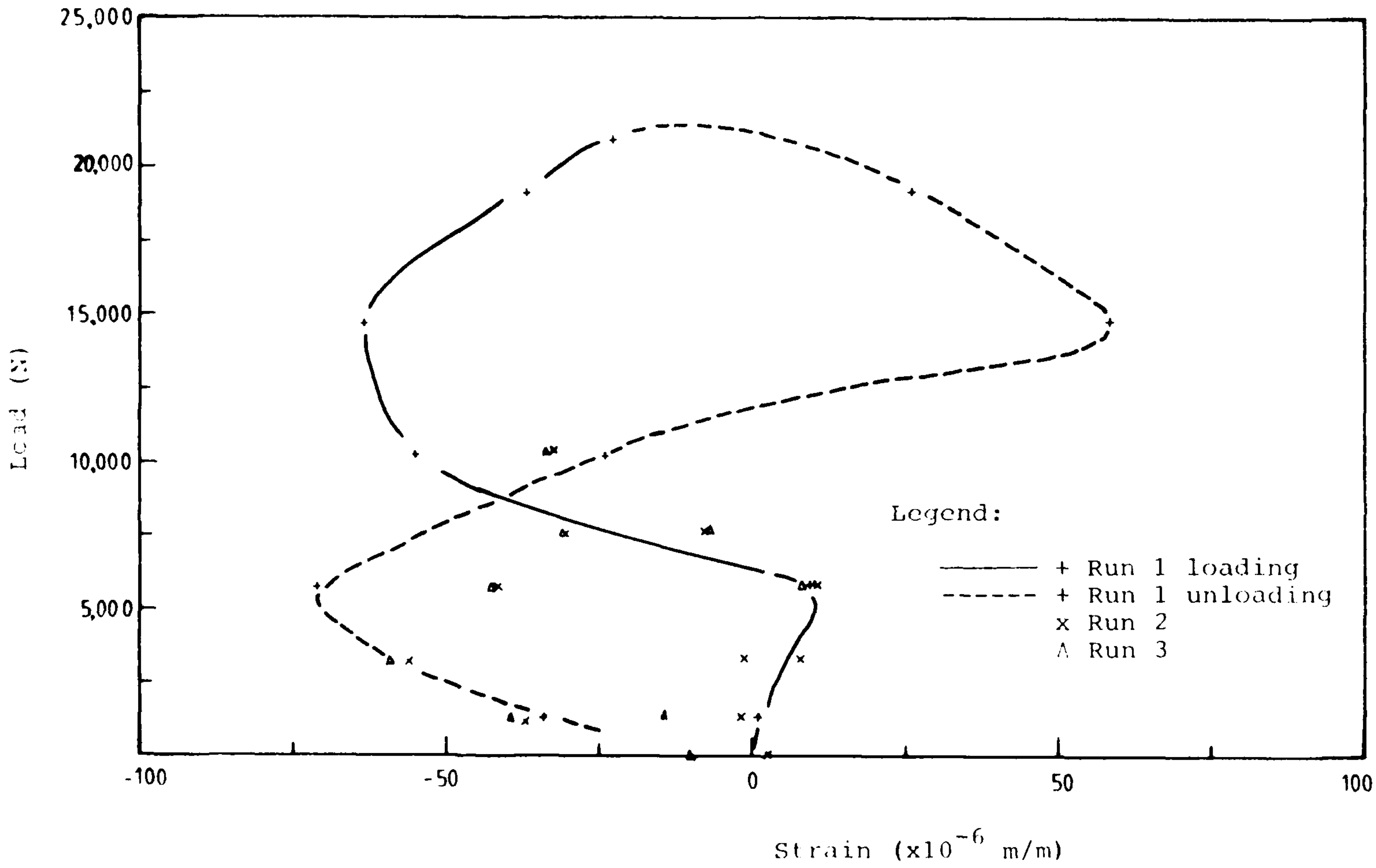

FIG. 10 LOAD VERSUS STRAIN FOR GAUGE POSITION B

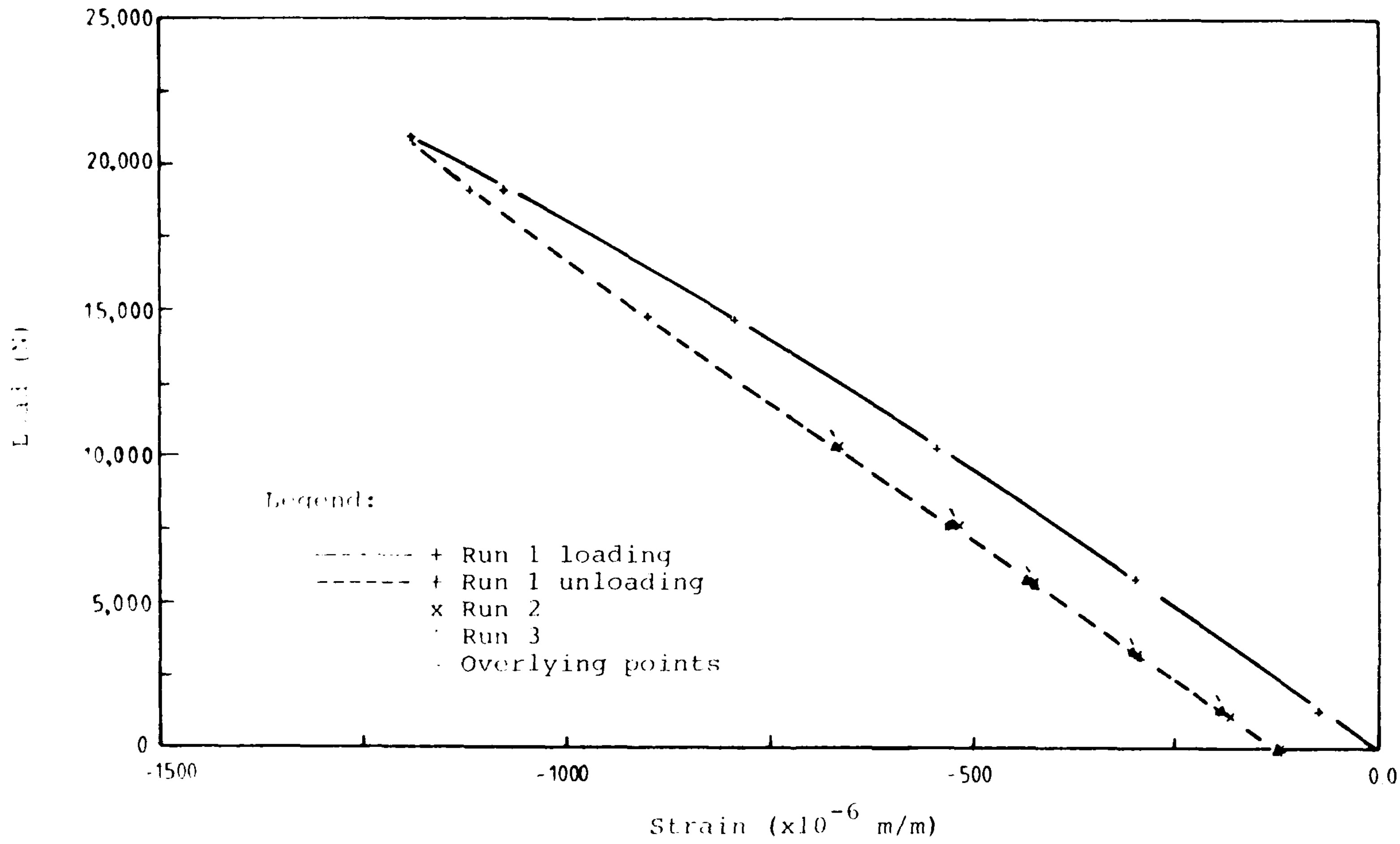

FIG. 11 LOAD VERSUS STRAIN FOR GAUGE POSITION C

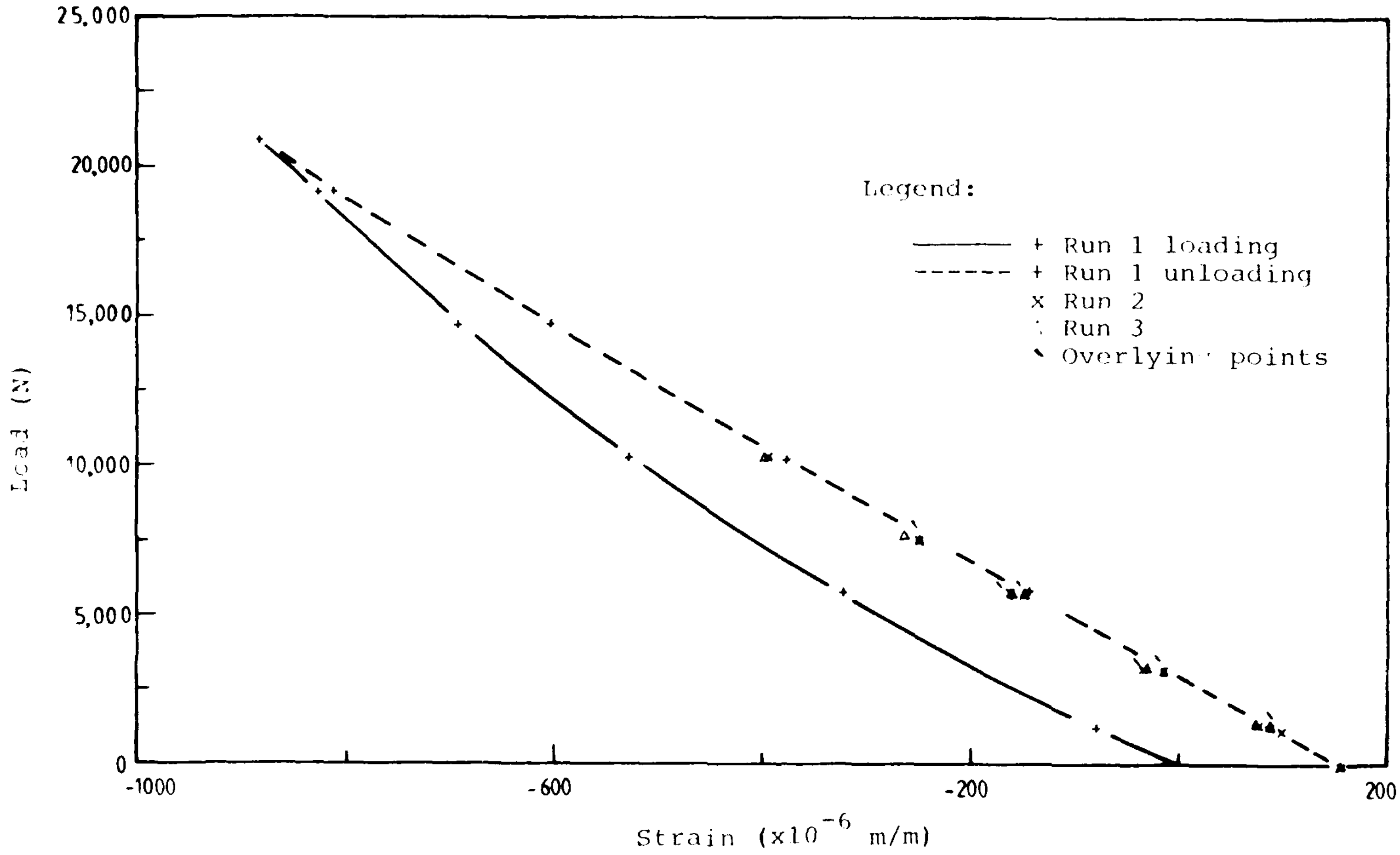

FIG. 12 LOAD VERSUS STRAIN FOR GAUGE POSITION D

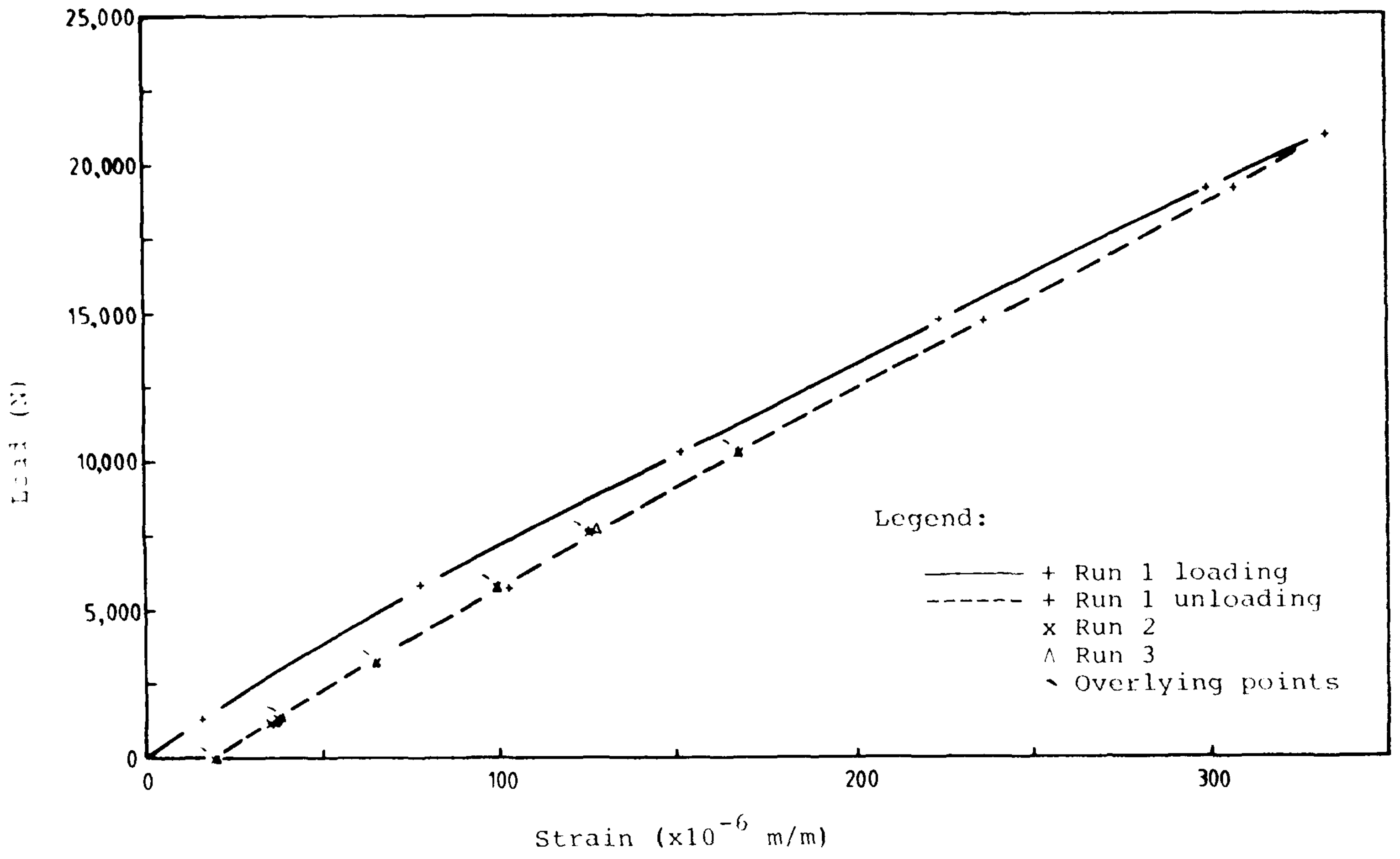

FIG. 13 LOAD VERSUS STRAIN FOR GAUGE POSITION E2

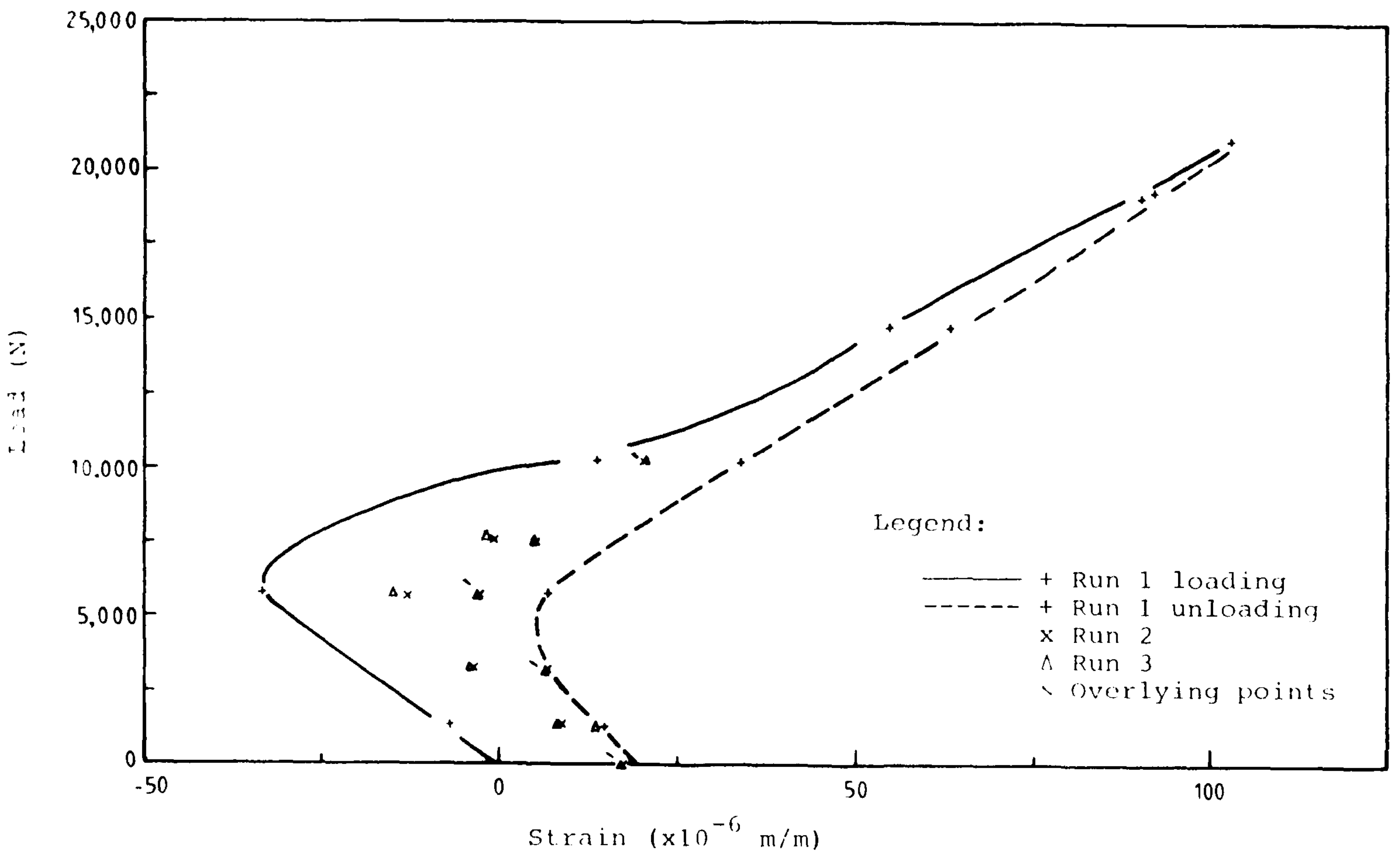

FIG. 14 LOAD VERSUS STRAIN FOR GAUGE POSITION F

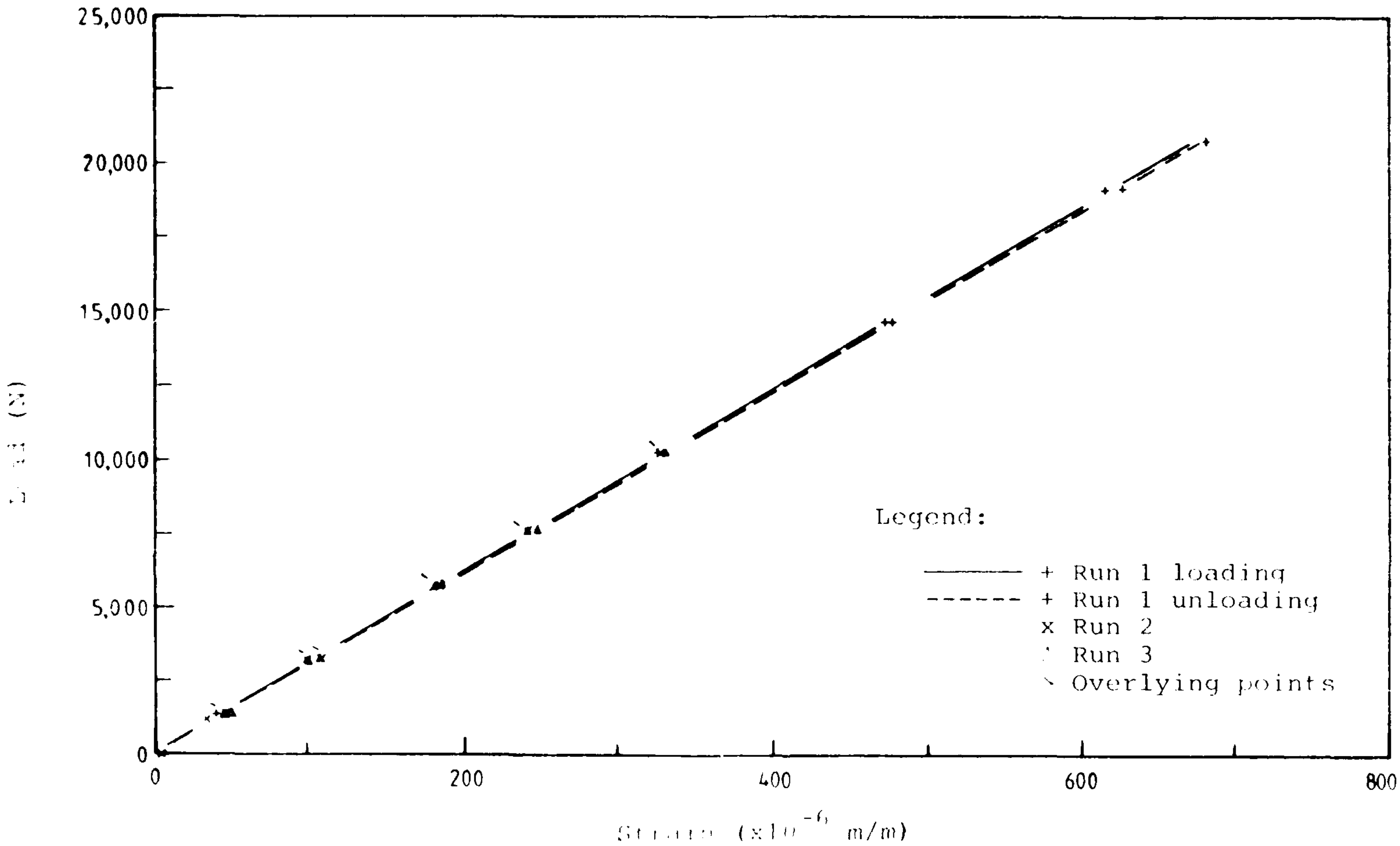

FIG. 15 LOAD VERSUS STRAIN FOR GAUGE POSITION G

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16. Abstract

A Diverless Helicopter Weapon Recovery System (DHWRS) has been strain gauged and subjected to ground calibration loadings.

A regression analysis has been carried out on the load/strain data and equations relating applied load to measured strain are presented for several locations, including the critical position on the aft ring.

Stress levels for a load of 24050N were calculated from the load/strain data.

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